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Rank The Gases NO, NO2, N2O4, And N2O5 In Order Of Increasing Root-mean-square Speed At 0°C

Understanding the relative speeds of different gases at a given temperature is fundamental in fields such as chemistry, physics, and environmental science. When considering the gases nitric oxide (NO), nitrogen dioxide (NO_2), dinitrogen tetroxide (N_2O_4), and dinitrogen pentoxide (N_2O_5), determining their rank in order of increasing root-mean-square (rms) speed at 0°C provides insights into their kinetic behavior and molecular properties. This article explores how to rank these gases based on their rms speeds, considering molecular mass, temperature, and the principles of kinetic molecular theory.

Introduction to Root-Mean-Square Speed

What Is Root-Mean-Square Speed?

Root-mean-square speed is a measure of the average speed of particles in a gas, considering their velocity distribution. It is mathematically expressed as:

$$v_{rms} = \sqrt{\frac{3RT}{M}}$$

where:
- R is the universal gas constant,
- T is the absolute temperature in Kelvin,
- M is the molar mass of the gas in kilograms per mole.

This equation indicates that the rms speed depends directly on the temperature and inversely on the molar mass. The higher the temperature, the faster the molecules move; the heavier the molecules, the slower their rms speed.

Factors Influencing the Ranking of Gases

Molecular Mass and Its Role

The primary factor influencing rms speed at a constant temperature is molecular mass. Gases with lower molar masses move faster on average, given the same thermal energy distribution.

Temperature Considerations

Since all gases are considered at 0°C (273.15 K), the temperature factor remains constant across all gases in this comparison.

Structural and Chemical Composition

While molecular complexity and structure can influence other physical properties, for rms speed, the key factor is molar mass, assuming ideal gas behavior.

Calculating Molar Masses of the Gases

To effectively rank the gases, let's examine their molar masses:

1. **Nitric Oxide (NO):** Nitrogen (N) = 14.01 g/mol, Oxygen (O) = 16.00 g/mol

   Molar mass = 14.01 + 16.00 = **30.01 g/mol**

2. **Nitrogen Dioxide (NO_2):** Nitrogen (N) = 14.01 g/mol, Oxygen (O) = 16.00 g/mol

   Molar mass = 14.01 + (2 × 16.00) = 14.01 + 32.00 = **46.01 g/mol**

3. **Dinitrogen Tetroxide (N_2O_4):** Nitrogen (N) = 14.01 g/mol, Oxygen (O) = 16.00 g/mol

   Molar mass = (2 × 14.01) + (4 × 16.00) = 28.02 + 64.00 = **92.02 g/mol**

4. **Dinitrogen Pentoxide (N_2O_5):** Nitrogen (N) = 14.01 g/mol, Oxygen (O) = 16.00 g/mol

   Molar mass = (2 × 14.01) + (5 × 16.00) = 28.02 + 80.00 = **108.02 g/mol**

Since molar mass is inversely related to rms speed (at constant temperature), gases with lower molar masses will have higher rms speeds.

Order of Gases Based on Molar Mass and RMS Speed

Given the molar masses, the gases can be ranked in order of increasing molar mass as follows:

1. NO (30.01 g/mol)
2. NO_2 (46.01 g/mol)
3. N_2O_4 (92.02 g/mol)
4. N_2O_5 (108.02 g/mol)

Applying the relation $v_{rms} \propto \frac{1}{\sqrt{M}}$, the gases will be ranked in order of decreasing rms speed as:

1. NO (highest rms speed)
2. NO_2
3. N_2O_4
4. N_2O_5 (lowest rms speed)

Therefore, the order of increasing root-mean-square speed at 0°C is:

$N_2O_5 < N_2O_4 < NO_2 < NO$

Final Ranking of Gases in Order of Increasing RMS Speed at 0°C

Based on the calculations and principles outlined, the gases can be definitively ranked as:

1. **N_2O_5 (Dinitrogen pentoxide)**
2. **N_2O_4 (Dinitrogen tetroxide)**
3. **NO_2 (Nitrogen dioxide)**

4. **NO (Nitric oxide)**

This order reflects the inverse relationship between molar mass and rms speed at a constant temperature.

Practical Implications of RMS Speed Rankings

Diffusion and Effusion

Gases with higher rms speeds diffuse and effuse faster. For example, NO, with the highest rms speed, will diffuse more rapidly than N_2O_5 under similar conditions.

Reaction Kinetics

The kinetic energy distribution influences reaction rates. Gases moving faster on average may react more quickly or participate differently in gas-phase reactions.

Environmental and Industrial Applications

Understanding these speed differences is vital in designing processes like gas separation, pollution control, and chemical manufacturing where gas flow and mixing are crucial.

Summary

To summarize, when ranking the gases NO, NO_2, N_2O_4, and N_2O_5 in order of increasing root-mean-square speed at 0°C, the key is their molar masses. Since all are at the same temperature, the gas with the lowest molar mass has the highest rms speed. The final order is:

$N_2O_5 < N_2O_4 < NO_2 < NO$

This ranking underscores the fundamental principle that lighter gases move faster on average at a given temperature, a cornerstone concept in kinetic molecular theory.

Conclusion

Understanding the relationship between molar mass and rms speed allows scientists and engineers to predict the behavior of gases in various settings. By knowing that N_2O_5, with the highest molar mass, has the lowest rms speed, and NO, with the lowest molar mass, has the highest, we can better interpret phenomena such as diffusion rates, reaction kinetics, and gas flow characteristics at 0°C. This knowledge is essential in fields ranging from atmospheric science to industrial chemistry, ensuring efficient and effective application of gas properties.

If you need further explanations or have specific questions about gas kinetics or related topics, feel free to ask!

Frequently Asked Questions

How do you determine the order of gases like NO, NO_2, N_2O_4, and N_2O_5 based on their root-mean-square speed at 0°C?

The root-mean-square speed (u_{ms}) of gases depends on their molar mass, with lighter gases moving faster. To order these gases, compare their molar masses; lighter gases have higher u_{ms}. Since the gases are related (NO, NO_2, N_2O_4, N_2O_5), their molar masses increase with the number of oxygen atoms, so the order is from lightest to heaviest.

What is the mathematical relationship between molar mass and root-mean-square speed for gases at a given temperature?

The root-mean-square speed u_{ms} is given by the equation u_{ms} = sqrt(3RT/M), where R is the gas constant, T is temperature, and M is the molar mass. This shows that u_{ms} is inversely proportional to the square root of the molar mass, so heavier gases have lower root-mean-square speeds.

At 0°C, which of the gases NO, NO_2, N_2O_4, and N_2O_5 has the highest root-mean-square speed?

The gas with the lowest molar mass has the highest root-mean-square speed. Since NO (molar mass approx. 30 g/mol) is the lightest among these gases, it will have the highest root-mean-square speed at 0°C.

Arrange the gases NO, NO_2, N_2O_4, and N_2O_5 in order of increasing root-mean-square speed at 0°C.

The order from lowest to highest root-mean-square speed is N_2O_5 < N_2O_4 < NO_2 < NO, since the molar masses increase in that sequence.

Why does the molar mass affect the root-mean-square speed of gases at a constant temperature?

Because the root-mean-square speed is inversely related to the square root of molar mass, lighter molecules move faster than heavier ones at the same temperature, affecting diffusion rates, effusion, and kinetic energy distribution.

Additional Resources

Rank the gases NO, NO_2, N_2O_4, and N_2O_5 in order of increasing root-mean-square (rms) speed at 0°C.
This question invites a detailed exploration of the kinetic properties of these nitrogen oxides, a class of gases with significant environmental and industrial importance. Understanding their molecular characteristics—particularly their root-mean-square speeds—is fundamental in fields ranging from atmospheric chemistry to process engineering. In this article, we dissect the factors influencing molecular speed, analyze the specific gases in question, and ultimately establish their relative ranks based on the physics governing molecular motion.

Introduction to Molecular Speeds and Kinetic Theory

The Significance of Root-Mean-Square Speed

The root-mean-square (rms) speed of a gas molecule is a statistical measure of its average molecular velocity, derived from the kinetic theory of gases. It represents the square root of the average of the squares of individual molecular speeds, providing a meaningful measure of the kinetic energy distribution within a gas sample. The rms speed (v_{rms}) is given by the equation:

$$
v_{rms} = \sqrt{\frac{3RT}{M}}
$$

where:
- R is the universal gas constant ($8.314\, \mathrm{J\, mol^{-1}\, K^{-1}}$),
- T is the temperature in Kelvin,
- M is the molar mass of the gas in kilograms per mole.

This equation reveals that, at a constant temperature, the rms speed is inversely proportional to the square root of the molar mass of the gas. Consequently, lighter gases move faster on average than heavier ones at the same temperature.

Impact of Temperature and Molar Mass

Since all gases are considered at 0°C (273.15 K), the temperature is constant for our comparison. Therefore, the key variable influencing the rms speed among the gases in question is their molar mass. The lighter the molecule, the higher its rms speed. This relationship forms the foundation for ranking gases based on molecular weight.

Analyzing the Gases: NO, NO_2, N_2O_4, and N_2O_5

Molecular Structures and Molar Masses

To determine their relative rms speeds, we first examine the molecular structures and molar masses of each gas:

- Nitric oxide (NO):
- Composition: 1 nitrogen atom + 1 oxygen atom
- Molar mass: $14.01 + 16.00 = 30.01\, \mathrm{g/mol}$

- Nitrogen dioxide (NO_2):
- Composition: 1 nitrogen + 2 oxygen atoms
- Molar mass: $14.01 + 2 \times 16.00 = 46.01\, \mathrm{g/mol}$

- Dinitrogen tetroxide (N_2O_4):
- Composition: 2 nitrogen + 4 oxygen atoms
- Molar mass: $2 \times 14.01 + 4 \times 16.00 = 92.02\, \mathrm{g/mol}$

- Nitrogen pentoxide (N_2O_5):
- Composition: 2 nitrogen + 5 oxygen atoms
- Molar mass: $2 \times 14.01 + 5 \times 16.00 = 108.01\, \mathrm{g/mol}$

From these values, it becomes evident that the molar mass increases with the number of oxygen atoms attached to nitrogen.

Calculating the Rank Based on Molar Mass and RMS Speed

Applying the RMS Speed Formula

Given that all gases are at the same temperature, the relative rms speeds depend on the inverse square root of their molar masses:

$$
v_{rms} \propto \frac{1}{\sqrt{M}}
$$

Therefore, the gases with lighter molar masses will have higher rms speeds.

Order of Increasing RMS Speed

Using the molar masses:

Gas	Molar Mass (g/mol)	In kg/mol	$v_{rms} \propto 1/\sqrt{M}$
NO	30.01	0.03001	Highest
NO_2	46.01	0.04601	Next
N_2O_4	92.02	0.09202	Lower
N_2O_5	108.01	0.10801	Lowest

Hence, the gases rank in order of increasing rms speed as:

$N_2O_5 < N_2O_4 < NO_2 < NO$

or, equivalently,

$N_2O_5 < N_2O_4 < NO_2 < NO$

Deeper Insights into Molecular Motion and Factors Affecting Speed

Effect of Molecular Size and Structure

While molar mass is the primary determinant, molecular shape and internal degrees of freedom can influence kinetic properties subtly. For instance, N_2O_5, being a larger, more complex molecule with potential for internal vibrational modes, may have slightly different kinetic behavior, but these effects are minor compared to the mass effect at the molecular level.

Temperature and Real-World Variations

Although the calculation assumes an idealized scenario at 0°C, real-world conditions may introduce deviations due to intermolecular interactions, phase behavior, or non-ideal gas effects. Nonetheless, the fundamental inverse square root relationship remains valid for gases at low pressures and moderate temperatures.

Implications in Atmospheric and Industrial Contexts

Understanding the relative rms speeds aids in predicting diffusion rates, reaction kinetics, and transport phenomena. For example, lighter gases like NO diffuse faster in the atmosphere than heavier oxides like N_2O_5, influencing pollution dispersion and chemical reaction rates.

Conclusion and Summary

In summary, the gases NO, NO_2, N_2O_4, and N_2O_5 can be ranked in order of increasing root-mean-square speed at 0°C based on their molar masses. Since rms speed is inversely proportional to the square root of molar mass, the lightest gas, nitric oxide (NO), exhibits the highest rms speed, and the heaviest, nitrogen pentoxide (N_2O_5), has the lowest.

Final order of increasing rms speed:

$N_2O_5 < N_2O_4 < NO_2 < NO$

This analysis underscores the central role of molecular mass in kinetic behavior, reinforcing core principles of the kinetic theory of gases. Such insights are crucial in environmental modeling, chemical engineering, and understanding molecular dynamics in various scientific domains.

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